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Using Electromyography to better understand the mechanisms behind Kohnstamm Phenomenon

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Abstract

The Kohnstamm phenomenon occurs when continued use of a muscle causes involuntary movement of that muscle after relaxation, leading to a feeling of lightness in the limb. The phenomenon can be observed in the arms when one pushes the outside of the hand against a surface for a prolonged period of time and then relaxes, and the arm then involuntarily raises and the arm begins to feel incredibly light. This project measures muscular effort using force plates and records muscle activity via EMG to reveal more information behind the Kohnstamm phenomenon, as well as address the mechanisms in the human body that contribute to the phenomenon. To quantify the effect, subjects were instructed to push against a door frame with force sensors attached, giving maximal effort for 30 seconds. Subjects repeated the experiment at two different frame widths (1.00m and 1.25m), which were presented in random order. While research is ongoing, our preliminary results found that the majority of subjects experienced the phenomenon, but about 15% of subjects did not. Most who experienced the phenomenon self-reported that the effect was greater at the narrower frame width. This observation, coupled with EMG analysis, suggests that the phenomenon occurs from re-engagement of shoulder muscles, especially the supraspinatus, following the end of the sustained contraction.

Introduction

The “Kohnstamm phenomenon” refers to the phenomenon that results when continued use of a muscle causes a feeling of lightness in the limb along with involuntary movement of the muscle once it is relaxed after the contraction. For example, the phenomenon commonly occurs when a person pushes the outside of the hand with a consistent force against an unmoving surface for a prolonged period of time, around 30-60 seconds, while keeping the arms straight. This motion engages the muscles of the shoulder in a prolonged, isometric contraction. Following relaxation after the hold, the arms will often involuntarily raise and to feel incredibly light, feeling as if they are floating.[1] This phenomenon is relevant to understanding muscle recruitment during involuntary and voluntary movements in humans. There are many diseases that cause involuntary movement, like Parkinson’s disease or Huntington’s disease. The Kohnstamm phenomenon provides an interesting opportunity to to investigate the mechanisms behind involuntary movement, and potentially providing insight to physiological processes that relate to proprioception and the neural control behind voluntarily stopping and preventing involuntary movements in humans.[2]

The exact mechanisms that cause the Kohnstamm phenomenon are not fully understood. There are theories such as sustained motor unit recruitment causing contraction post relaxation of the limb.[14] A negative position feedback, where the central nervous system detects a discrepancy between the location of the arm and where the muscle spindle input believes the arm should be.[11] Purely central persistence of a motor command is another theory, where the central nervous system maintains a motor command in the absence of sensory feedback.[3] The phenomenon can also be observed in other parts of the body as well, such as the knee, ankle, wrist and hip.[4] It is believed this phenomenon can be more easily observed in joints of the body that are more proximal to the midline of the body as opposed to distal joints.

The Kohnstamm phenomenon is not observed in all people, as around 75% of people will experience the effect when following these steps, but roughly a quarter of healthy humans do not experience the effect.[6,7] Why some individuals experience the phenomenon, but others do not is not understood. This project will allow us to look at if there may be a pattern or reason behind why this phenomenon only occurs in some and why some do not experience it. We also wanted to quantify the percentage of subjects who experienced this effect, and see if we can find any patterns among the people who experience the effect and those that do not. To address these questions, we looked at both the force data collected (force generated during the hold and fatigue experienced by the subjects), and recorded EMG data to examine patterns of muscle recruitment that may provide hints to the reasons why this phenomenon isn’t experienced by some. One initial hypothesis is that we expected to see a much lower average force exerted by people who don’t experience this effect, perhaps because the subjects who didn’t experience the effect did not exert as much force as those who did, or perhaps didn’t fatigue the muscles enough to experience the effect.[8] The two different degrees of shoulder abduction may also have some impact on this effect, perhaps the occurrence and intensity of the effect is dependent on shoulder position, so investigating the differences between them was key as well.

To understand the electrical activity of the muscles during this phenomenon, we used EMG (electromyography) to measure the activity of the deltoid, which is considered the primary abductor of the shoulder joint, and supraspinatus muscles of the rotator cuff, which help initiate and stabilize movements of the shoulder.[5] These muscles are both vital in the abduction of the arm, and are the likely contributors to the Kohnstamm phenomenon.[10] As these two muscle groups contribute differently to abduction (lateral raising) of the shoulder, tests were done at different angles of abduction of the shoulder to measure if the angle of the arm and shoulder had an effect on the phenomenon and its strength. This allowed us to see if there were discrepancies in EMG activity between the two alignments, as well as seeing how the different alignments affected force outputs and motor unit recruitment in subjects. I hypothesized that the narrow alignment of the force plates would see a higher occurrence of the phenomenon and a greater force exerted by the muscles, since the narrow alignment would allow for an easier and stronger application of force. I also hypothesized that the narrow alignment would increase the intensity of the effect in those who experienced it, as opposed to the wider alignment.

Methods and Materials

This research was approved by the UNCA IRB for human subjects research [protocol 1971486-1]. A total of n=76 volunteer subjects were collected from a convenient sample of UNCA students to be a part of this experiment. All of the participants were briefed on what was involved with participating in the experiment, and all participants read and signed an informed consent form before data was collected.

Tests were done to measure force output each participant exerted, at two different widths of frame – a wide alignment of 1.25 meters, and a narrow alignment of 1 meter (figure 1). The frame widths were presented in random order (wide or narrow first). Wooden frames were placed inside the door frames of the labs of Zeis Hall at UNCA, using a pegboard frame that had several holes to hang force plates (Vernier Systems FP-BTA), which allowed the force plates to be raised or lowered to accommodate the differences in height among the participants. At each width, plates were always positioned so that the back of the subjects' hands would hit squarely in the center of the force plate.

Participants were instructed to stand in the middle of the frame and then to press against the force plates on either side of them with the back of their hands, keeping their arms straight and pushing with as much force as comfortably possible for thirty seconds. Prior to contraction, participants were asked to relax their shoulders so a period could be recorded to provide baseline EMG levels when viewing the muscles were at rest. After thirty seconds of continual pushing against the frame, participants would step backwards and were told to relax their arms, and experience whatever sensation they felt. All participants were asked to describe the phenomenon felt and report any sensations they felt in their arms. The researchers verified if any movement of the shoulders occurred or raising of the arms occurred, and if there were any behaviors that would interfere with the quality of data generated during the trial (ex. some subjects voluntarily moved around a great deal upon feeling the effect; others tried to move away before they had time to experience the effect).

After participants had performed the test in both the wide and narrow alignment, they were asked to self-report which width they felt the phenomenon was stronger (or if equal, or if the effect was nonexistent), and if the Kohnstamm effect was experienced in both alignments. The order of the wide and narrow alignments was randomized for every participant.

Figure 1. Standard position of the subjects during the experiment, showing [A] the narrow (1.0m) and [B] wide (1.5m) frame widths.

Force Data

Logger Pro version 3.16.2 was used for recording force data from the two force plates (Vernier Systems FP-BTA), as well as for analysis and quantification of force data. Variables calculated and included for analysis are the average force (N) exerted during the course of the experiment, and the total force integral (N·sec) under the force curve for the duration of the experiment. To quantify fatigue, average forces (average force over periods of ~5 seconds) were calculated for the force exerted shortly after the beginning of the experiment, and again just prior to the end of the experiment. Fatigue percentage was calculated by dividing the ending force value by the beginning force value.

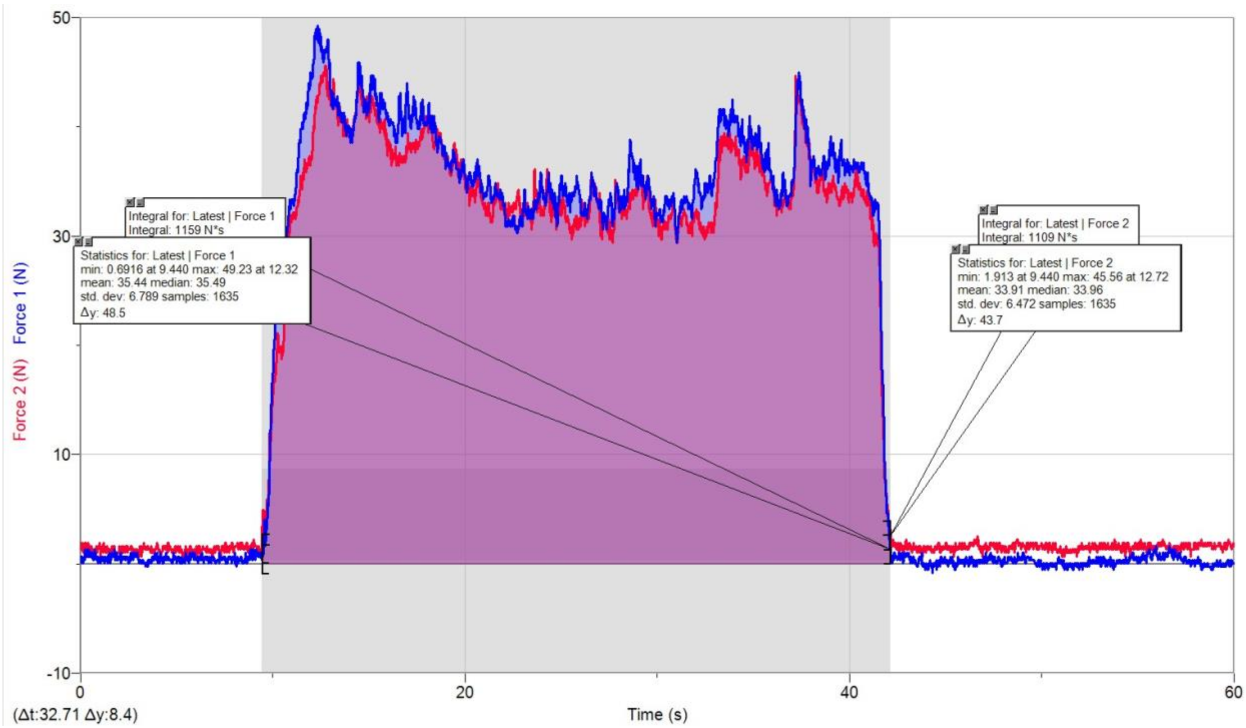


Figure 2. An example of force data recorded. Force 1 corresponds to the right arm, and force 2 to the left arm. Includes all statistics recorded using Logger Pro 3.16.2.

Muscle EMG activity

EMG data was recorded using the Biopac MP36 data-logger and MP160 EMG electrodes, and BioPac Student Lab (BSL 4.1) software. Participants in the EMG study had skin surface electrodes attached over their right deltoid and supraspinatus to measure electromyography data during the experiment (figure 3). The force data and the EMG data were recorded simultaneously. Two different channels were used to record the two different muscles, with channel 1 corresponding to electrodes placed over the deltoid muscle, and channel 2 electrodes were placed over the supraspinatus (just above the spine of the scapula). The electrodes for channel 2 also likely detected electrical signals from the superior fibers of the trapezius, and possibly the levator scapulae. The red and white are the positive and negative electrodes, and are placed proximal to each other on the deltoid and supraspinatus. The black electrode, the ground, was placed farther down the deltoid and placed at the base of the neck in the measuring of the supraspinatus. Placements of the electrodes were determined based on where they would most effectively measure nerve activity of the muscles, and the ground was placed to reduce noise in readings, giving a more accurate reading. A clip was also attached to the shirt of participants, in order to hold the wires in place reliably.[6]

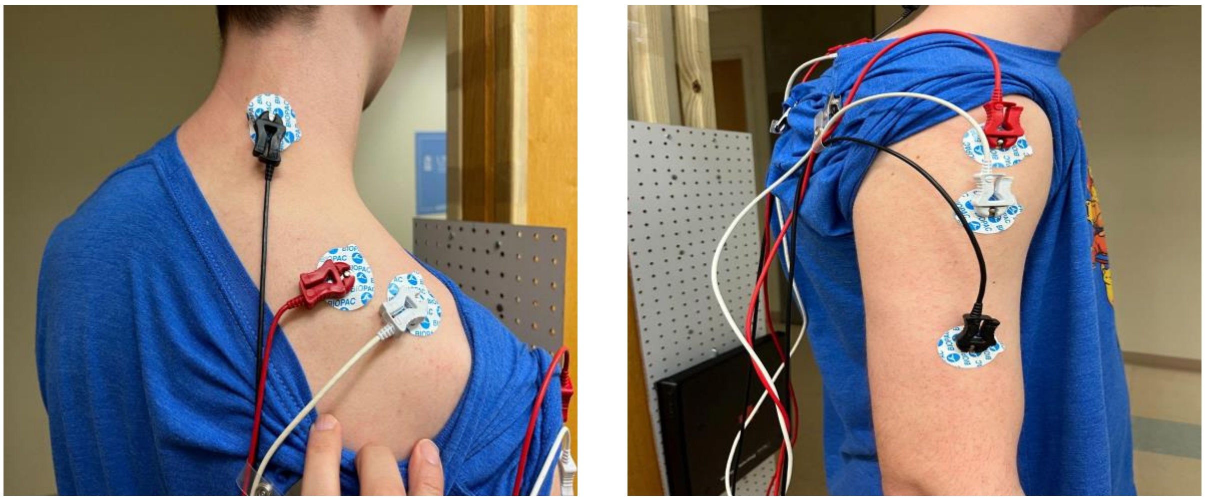


Figure 3. (A) Electrode placements on the supraspinatus.(B) Electrode placement on the deltoid.

EMG analysis was performed using Biopac student lab 4.1. In order to eliminate signal fluctuation caused by movement of the wires of the electrodes or any other anomalies in the data, the infinite impulse response filter [high and low pass] feature available in the Biopac software was used to transform the original readings. All analysis was performed on these transformed EMG readings. Examples of transformed EMG readings can be seen in Figure 4.

The electrical activity of the muscles was analyzed at 5 different times during the experiment. The periods sampled were (1) pre-contraction of the muscles, when the muscles were relaxed [“pre-”], (2) shortly after beginning of forceful muscle contraction [“early”], (3) shortly before the end of the thirty seconds of muscle contraction ["late”], (4) the period relaxation immediately after contraction ceased [“post1”], and (5) a few seconds after the post contraction relaxation, during the time when the Kohnstamm phenomenon was expected to be observed [“post2”]. These periods can be seen in figure 4. Because normalized data have a mean of zero, the standard deviation during these time periods was taken to represent the average motor unit recruitment (muscle activity and engagement). A greater standard deviation indicates greater electrical activity produced by the muscle.

The data I collected was supplemented with data from previous testing and data collection by Rafael Serra in spring of 2024.[9] Participants in Serra's experiment performed the same experiment, measuring force and EMG data at both the wide and narrow widths in the doorframe, and measuring EMG data of the deltoid and supraspinatus of the right arm using equivalent EMG placement.

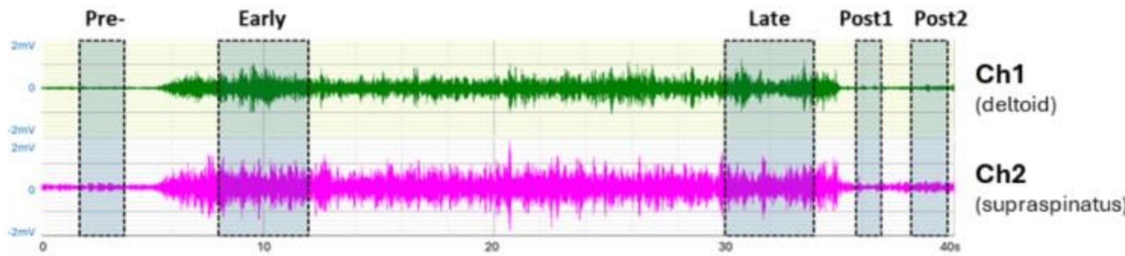


Figure 4. An example of transformed EMG data recorded during experiment and the 5 time windows that were measured for analysis from channels 1 and 2, which correspond to the deltoid and supraspinatus respectively.

Results

Of the total of n=76 participants included, n=60 (79%) of the participants experienced the Kohnstamm phenomenon in at least one of the tests, while n=16 (21%) of subjects did not self-report or show any physical evidence of experiencing the Kohnstamm effect. Many of the participants (n=49, 65%) experienced the phenomenon at both the wide and narrow alignments, although some (n=11) only experienced the effect at the narrow frame. No subject reported experiencing the effect at the wide frame, but not the narrow. Of those who experienced the effect at both widths, n=38 (78%) of subjects self-reported that they felt a greater effect in the narrow alignment, n=7 (14%) reported a greater effect in the wide alignment, and n=4 (8%) reported an equal effect in both (figure 5).

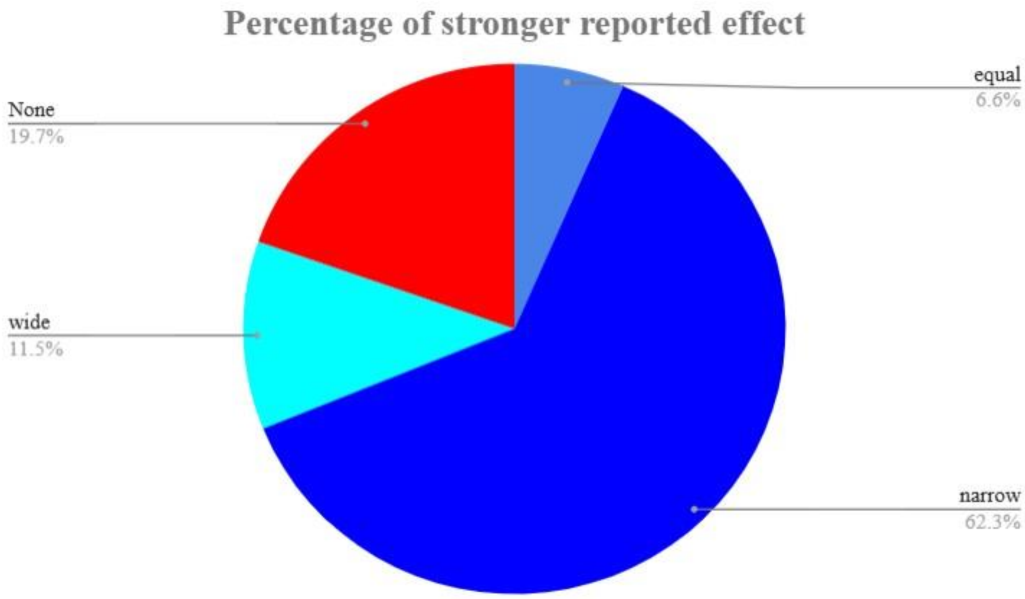


Figure 5. Percentage of participants who reported a stronger effect in narrow width, wide width, an equal effect in both, or did not demonstrate an effect in either alignment.

Prior tests have shown that there is no significant difference between force exerted by the left and right arms, so all data was taken for the right arms of participants.[13] A two sample t-test assuming unequal variance was used to compare the average force and fatigue percentage of all participants. The t-test for average force showed there was no significant difference in force exerted (t = 1.007, df = 58, P= 0.31). The t-test for average fatigue showed there was not a significant difference between the wide and narrow tests (t = 1.690, df = 58, P= 0.09) [figure 6].

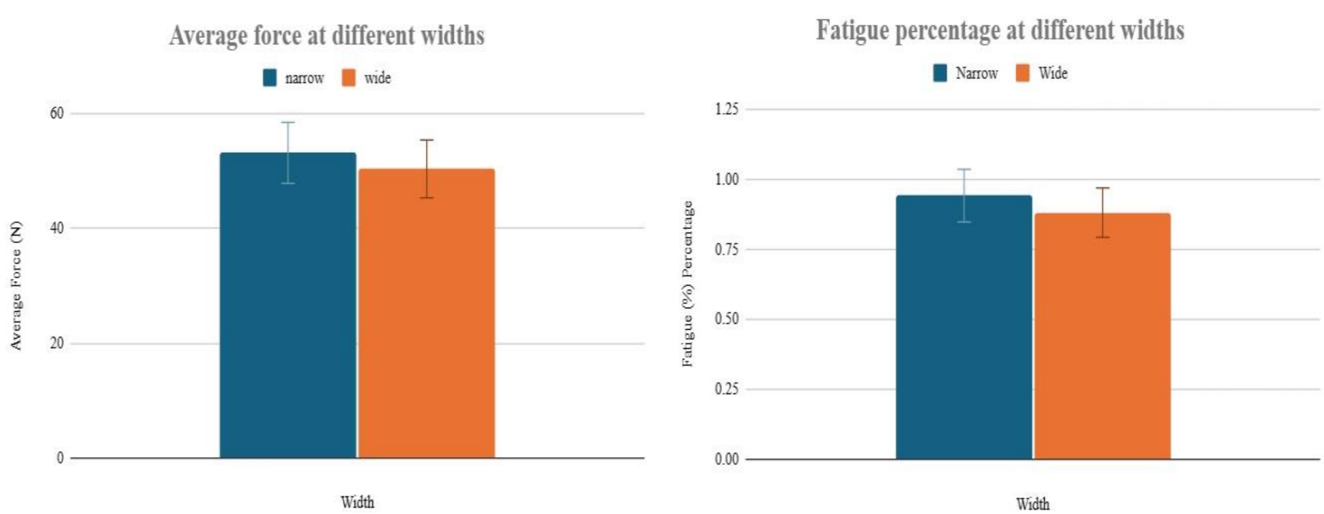


Figure 6. (A) Average force exerted during the narrow and wide tests among all participants. (B) Fatigue percentage of the narrow and wide tests among all participants.

Two sample t-tests were run on the average force and fatigue of those who displayed the phenomenon and those who did not at both widths. The results for the narrow width showed no significant difference between people who experienced the phenomenon and those who did not in force produced throughout the experiment (t = 0.5, df = 22, P= 0.611). Likewise, the t-test on the average force of the wide width also resulted in no significant difference (t = 0.2, df = 55, P= 0.810). This indicates the people who did not experience the effect were generating forces that compared to those that did (figure 7).

Similar t-tests done on fatigue showed no significant difference in fatigue between those who did and did not experience the phenomenon at the narrow frame (t = -0.3, df = 26, P= 0.756). The wide width also showed no significant difference between those that did and did not experience the phenomenon (t = -0.9, df = 33, P= 0.373). The subjects who did not experience the Kohnstamm phenomenon were not any more or less fatigued than those that did (figure 7).

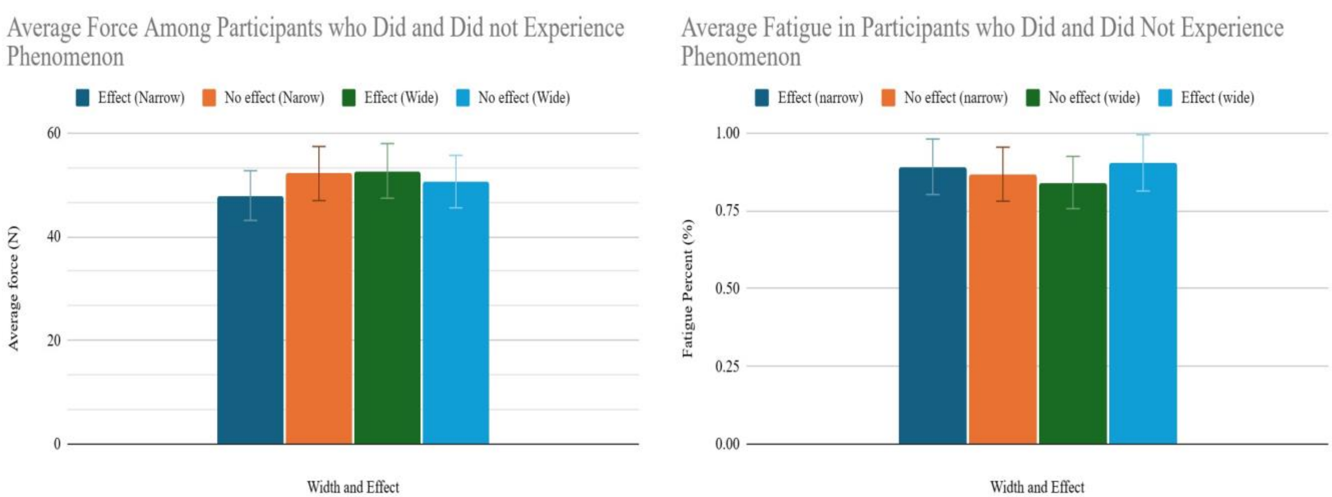


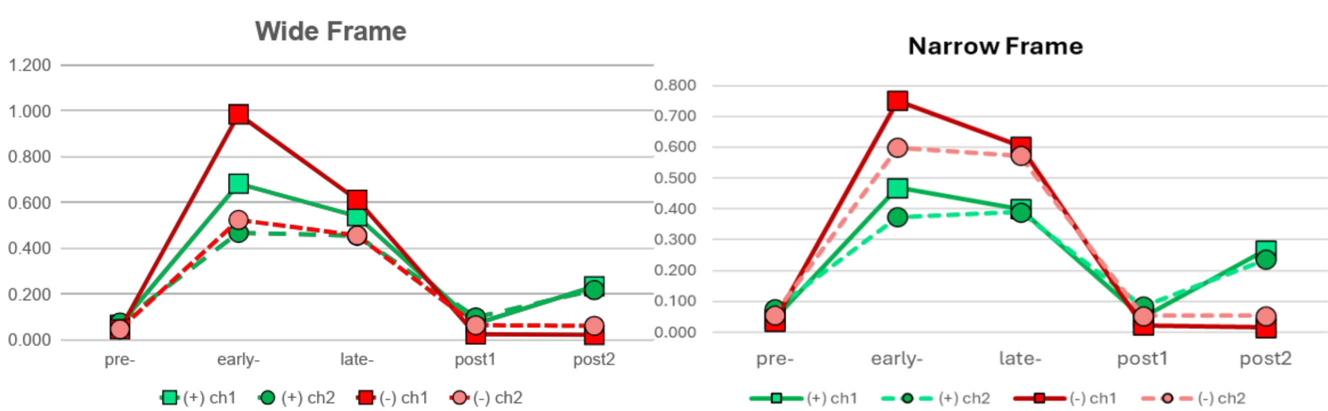
Figure 7. (A) Average force exerted by the participants who did and did not experience the phenomenon from both widths. (B) Average fatigue experienced by participants who did and did not experience the phenomenon.

Analysis was conducted to compare the forces and fatigue between those who described the effect as being greater at the wide or narrow frame. In the group of participants who reported the narrow effect as stronger, paired t-tests showed that there was no significant difference in average force exerted (t = 0.9, df = 35, P= 0.400), but there was a significant difference in fatigue experienced (t = 3.0, df = 35, P= 0.005), with participants experiencing significantly more fatigue (% drop in force production) at the wide frame. However, for the group that reported the wide width as producing the stronger effect, there was no significant difference in force exerted (t = -2.2, df = 6, P= 0.07), or in fatigue (t = -0.6, df = 6, P= 0.57). The sample size of this group is small, so these results should be viewed with caution, but these results suggest that people who experienced the greater effect at the wide frame may have been pushing with greater effort at the wider frame.

EMG Results

The primary results of the EMG studies are shown in figure 8, and the statistical significance of paired t-tests are summarized in table 1. The results showed there were no significant differences in EMG activity between the period of relaxation prior to the hold, and the relaxation period just after the hold. This suggests that the subjects did fully relax the muscles following the prolonged hold, in both the subjects who did and did not experience the effect. The Kohnstamm effect occurs after a period of full muscle relaxation.

In the subjects that experienced the Kohnstamm effect, there was a significant increase in EMG activity after the relaxation period, which is associated with the raising of the arms that follows the Kohnstamm phenomenon. This shows that there is a relaxation period, where the muscle ceases and contracts and has little EMG activity before the phenomenon then causes a re-activation of these muscles. No similar significant increase in muscle EMG activity occurred in the people who did not experience the effect.



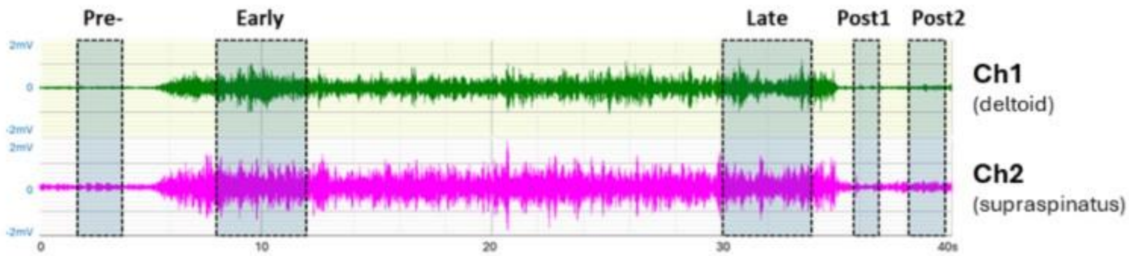


Figure 8 Mean EMG readings over 5 time periods (see sample EMG tracing at bottom). (+) indicates subjects who experienced Kohnstamm effect, (-) did not experience the effect.
Ch1 = deltoid, Ch2 = supraspinatus.

	NARROW			WIDE		
NO EFFECT	**early-late**	**pre-post1**	**post1-post2**	**early-late**	**pre-post1**	**post1-post2**
ch1	0.278	0.424	0.134	*0.017*	0.259	0.416
ch2	0.682	0.627	0.979	0.238	0.462	0.713
(+) EFFECT						
ch1	0.097	0.501	*0.000*	0.104	0.493	*0.001*
ch2	0.344	0.354	*0.000*	0.581	0.145	*0.000*

Table 2. Results (p-values) of paired T-tests. Significant results are highlighted in red.

The EMG readings during the period of force production were significantly greater at wide frame for the deltoid (2-sample t-tests: ch1 early, $p<0.001$; ch1 late, $p=0.003$), but there was no effect of frame width on EMG for the supraspinatus (ch2 early, $p=0.37$; ch2 late, $p=0.76$). This suggests that the deltoid muscle group is more actively engaged at the wider frame, while the supraspinatus muscles exert roughly equal effort at both frame widths.

Discussion

With the mechanisms of the Kohnstamm phenomenon still not being fully understood, the aim of these tests was to see if we could come to a greater understanding of some of the trends behind what is causing this phenomenon. We wanted to see if there was significant difference in things such as fatigue or force exerted, and if that carried any significance in achieving the phenomenon. Several hypotheses were made about how specific things such as force exerted or width would affect the prevalence of the phenomenon.

We predicted that those who exerted more force on average were more likely to experience the effect than those who exerted very little force. None of our findings supported this hypothesis, as there were no significant differences in force or fatigue between the groups, and some of the individuals with highest average force outputs did not report any effect. We also did not find many significant differences in force generated between the two widths, as things such as force average and total force were not significantly different between all participants in both widths. In the small total number of participants that reported the wide as being the stronger effect, it is possible that the people who were reporting a stronger effect at the wide width were using more force than they were on narrow. We did not attempt analysis of the minimal forces that are needed to generate the effect, which could be an interesting future study.

One test that returned a significant difference was that people who reported the narrow effect as stronger had a significantly higher amount of fatigue in the wide alignment than the narrow alignment. This could be why there were many more people that reported the narrow effect as stronger, as more fatigue in the wide test could decrease the reported intensity that participants experienced.

In our analysis of the EMG data we found that the deltoid muscle in the wide alignment had a significantly higher EMG reading than the supraspinatus, but in the narrow alignment there was no significant difference. This shows that while there may not be one muscle that is significantly more responsible for the phenomenon in the narrow width, perhaps as the angle that the arms apply force at increases, the deltoid is doing more work. This means it will be more fatigued and have a higher EMG reading. People who reported the narrow effect as stronger also having more fatigue in their wide tests seems to support this as well.

We wanted to use the two different widths to see if they would cause the different muscles to be recruited at different levels. We hypothesized that in the more wide alignment, we would see more deltoid recruitment than in the narrow alignment. We also hypothesized that the supraspinatus would operate in the opposite way, where in the narrow alignment we would see more supraspinatus recruitment.

We did see that during the force production period in the wide test, deltoid EMG levels were significantly higher than the narrow tests. This supported our hypothesis, but in the supraspinatus, there was no significant difference between the two widths. We had believed that we may see a relationship between width and which muscles were recruited, showing that the phenomenon can affect muscles more selectively depending on the angle of the force. Our findings in the deltoid may support this idea that the angle affects which muscle is reactivated by the phenomenon, but the fact that the supraspinatus has no significant difference does not support this idea. However, the position of the electrodes over the supraspinatus will also pick up signals from the upper part of the trapezius, and it is possible that the different recruitment of these 2 muscles at the different frame widths produces a relatively stable EMG reading.

These results are what make the EMG levels during the phenomenon very interesting. In both the wide and the narrow tests, both muscles are recruited at similar levels, unlike during the initial voluntary contraction. In contrast to the levels of recruitment in the voluntary contraction of the muscles earlier in data collection period, where the supraspinatus is immediately recruited at a higher level, when the phenomenon occurs, it recruits both muscles at similar levels. In people who experience the Kohnstamm phenomenon, there is a significant increase in the activity of both muscle groups that were recorded. This indicates that the effect occurs by lightly recruiting both muscle groups equally.

This research has some potential flaws that could cause data to be inaccurate or inconsistent. Electrodes are not always placed in the exact same spot, even though they were always placed on the correct muscle to measure them. Thus, it is difficult to compare EMG readings between 2 different individuals. Variation in electrode placement could also cause inconsistencies among EMG readings, as the small discrepancies between placement can lead to error.[12] In addition, studies have shown that EMG signals can sometimes be inconsistent in their readings, sometimes showing small discrepancies when placed in the exact same spots with the exact same actions being performed and measured.[13] In the measurements of force, plates were raised or lowered to a height which seemed to be most comfortable and efficient for them to push the back of their hand against the plate, but being off from the center or potentially having to hold their arms at any kind of angle that is uncomfortable could have affected their ability to properly apply force, and for the plate to properly read the force applied. Many of the tests done during this experiment returned insignificant values, which could potentially be contributed to our relatively small sample size.

This study also included data from almost entirely college students in a similar age range. This means it may not be as applicable to a general population, as it does not include a wide range of ages, which may have different levels of reporting this phenomenon, or have different patterns in the force or EMG readings. In addition, the subjectivity of participants reporting which width was stronger could lead to inaccuracies. Some participants may actively attempt to resist the phenomenon or be influenced by the reporting of others.

Further research into this phenomenon could include similar tests, with a wider age range, to test these findings among a more generalized population as opposed to primarily college age young adults. The phenomenon can also be observed in several other body parts, and testing on them could help to reveal trends behind the causes, and to see if EMG readings are similar across these different parts of the body.[13] It could also be useful to further test different muscles in the arm during this effect, as a complete understanding of how all the muscles that assist in the abduction of the arm could shine more light on the processes behind this phenomenon. Finding when and to what level different muscles are recruited could reveal information about how this phenomenon works to involuntarily activate muscles.

There are many diseases and disorders that can cause involuntary motion, or cause voluntary motion to be made much more difficult or even possible. The Kohnstamm phenomenon provides us a unique opportunity to attempt to observe and understand involuntary motion and how it works. With a further understanding of how involuntary motion and the restriction of voluntary motion affect the muscles, we could eventually grow to be able to treat these disorders or diseases in some way.

Acknowledgements

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References

1. McDonagh, M., & Parkinson, A. (2020, March 5). *Levitating arms: Unravelling the mystery*. The Physiological Society.
2. De Havas, J., Ghosh, A., Gomi, H., & Haggard, P. (2016, July 8). *Voluntary Motor Commands reveal awareness and control of involuntary movement*. Science Direct.
3. De Havas, J., Gomi, H., & Haggard, P. (2017). Experimental investigations of control principles of involuntary movement: a comprehensive review of the Kohnstamm phenomenon. Experimental Brain Research, 235(7), 1953–1997.
4. Allen, F., & O’Donoghue, Chas. H. (1927). The Post-Contraction Proprioceptive Reflex, Its Augmentation and Inhibition. Quarterly Journal of Experimental Physiology, 18(3), 199–242.
5. De Havas J, Ito S, Haggard P and Gomi H (2018) Low Gain Servo Control During the Kohnstamm Phenomenon Reveals Dissociation Between Low-Level Control Mechanisms for Involuntary vs. Voluntary Arm Movements. Front. Behav. Neurosci. 12:113.
6. Ivanenko, Y. P., Wright, W. G., Gurfinkel, V. S., Horak, F., & Cordo, P. (2005).

Interaction of involuntary post-contraction activity with locomotor movements. Experimental Brain Research, 169(2), 255–260.
7. Adamson, G., & McDonagh, M. (2004). Human involuntary postural aftercontractions are strongly modulated by limb position. European Journal of Applied Physiology, 92(3), 343–351.
8. De Havas, J., Ghosh, A., Gomi, H., & Haggard, P. (2015). Sensorimotor organization of a sustained involuntary movement. Frontiers in Behavioral Neuroscience, 9.
9. Serra, R. (2024). The Kohnstamm Phenomenon: Involuntary Movement Followed by Sustained Muscle Contraction. UNCA Journal of Undergraduate Research.
10. Lam, J. H., & Bordoni, B. (2019, January 20). Anatomy, Shoulder and Upper Limb, Arm Abductor Muscles. Nih.gov; StatPearls Publishing.
11. Bizzi, E., Accornero, N., Chapple, W., & Hogan, N. (1984). Posture control and trajectory formation during arm movement. The Journal of Neuroscience, 4(11), 2738–2744.
12. Mercer, J. A., Bezodis, N., DeLion, D., Zachry, T., & Rubley, M. D. (2006). EMG sensor location: Does it influence the ability to detect differences in muscle contraction conditions? Journal of Electromyography and Kinesiology, 16(2), 198–204.
13. Roberts, T. J., & Gabaldon, A. M. (2008). Interpreting muscle function from EMG: lessons learned from direct measurements of muscle force. Integrative and Comparative Biology, 48(2), 312–320.
14. Duclos, C., Roll, R., Kavounoudias, A., & Roll, J.-P. . (2007). Cerebral correlates of the “Kohnstamm phenomenon”: An fMRI study. NeuroImage, 34(2), 774–783.